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Solar greenhouse drying: A review

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ABSTRACT

Solar energy has been used for the preservation of agricultural produce since generations all over the world. Recent research on drying reveals the shortcoming of the open sun drying. In order to minimize the shortcoming of the open sun drying, various drying techniques are proposed. Among them previous effort on greenhouse dryer has been presented in this study. It can be used to do low temperature drying of cereal grains, fruits, vegetables, spices etc. The greenhouse dryer is operated in the two different modes of drying— natural convection and forced convection. Recently development of greenhouse dryers namely solar tunnel dryer, solar tent dryer, improved solar tunnel dryer, and roof type even span solar greenhouse dryer has been studied. An organized approach for the categorization of greenhouse dryers has evolved. A simulation model for drying performance proposed by authors has been studied. Products dried in the greenhouse dryer are found to be superior in quality as compared to those in open sun drying. In addition, the product is completely protected from external calamities such as rain, insects, and animals. All recent developments in greenhouse drying are emphasized in this communication.

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Contents

1. Introduction

Solar drying is the oldest way for the preservation of crops and it is practiced everywhere [1]. In natural drying or open sun drying, the crops are put on compact earthen floor, mat, concrete, floor, and road in the full sunny days. It is exposed to various contaminations—dirt, pest infestation, and loss by birds and beast. In addition, there is the possibility of aflatoxin contamination of crops like maize. Fig. 1 illustrates the drying of paddy on concrete floor. Open sun drying is also used to dry the marine products.

Nowadays, the demand for dried agricultural produce, marine products and, medicinal plants have increased considerably worldwide [2]. Naturally dried products are the cheapest whereas their quality is far below in the international standard. Therefore, open sun drying provides the opportunity to produce a higher quality of dried products [3]. Drying is the process of reduction of moisture upto a safe limit of moisture content. The percentage of dryness depends on the moisture content in the agricultural produce either on a wet basis or dry basis. Moisture content in the food/crop/agricultural produce is calculated based on dry and wet basis. Table 1 presents the safe limit of the various crops [4]. It leads to slow down the activity of enzymes, bacteria, yeasts, and moulds. In order to improve the quality and colour of the dried product, researchers have discovered various ways of drying—spray dryer, mechanical dryer, electrical dryer, solar dryer etc. Due to rapid increase in the price of conventional fuel and the depletion of it, solar energy emerges as a useful source of energy, which can be employed in the drying process. Prakash and Kumar have reviewed various existing solar dryers [5].There are mainly three types of solar drying systems: indirect, direct, and mixed dryer. Greenhouse dryer comes in the category of the direct solar drying and also sometimes mixed mode drying.

The greenhouse dryer is low cost, easy to fabricate and simple in design. This can be used in any part of the world. Initially

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Fig. 1. Drying of rough rice on concrete cemented floor [1].

Table 1
Details of moisture content of the various crops [4].

Crop	Initial moisture content (wb%)	Final moisture content (wb%)	Maximum allowable temp. (°C)
Paddy, raw	22–24	11	50
Paddy, parboiled	30–35	13	50
Maize	35	15	60
Wheat	20	16	45
Corn	24	14	50
Rice	24	11	50
Pulses	20–22	9–10	40–60
Oil seed	20–25	7–9	40–60
Green Peas	80	5	65
Cauliflower	80	6	65
Carrot	70	5	75
Green beans	70	5	75
Onion	80	4	55
Garlic	80	4	55
Cabbage	80	4	55
Sweet Potato	75	7	75
Potatoes	75	7	75
Chilies	80	5	65
Apricot	85	18	65
Apples	80	24	70
Grapes	80	15–20	70
Bananas	80	15	70
Guavas	80	7	65
Okra	80	20	65
Pineapple	80	10	65
Tomatoes	96	10	60
Brinjal	95	6	60

greenhouse dryers were used for the cultivation of the crops [6]. Yet it can also used for space heating, soil solarisation, poultry, and aquaculture. This creates an ideal atmosphere for the cultivation. Since two decades ago, researchers have discovered that it could also be used for low temperature drying. Therefore, greenhouse structure can be used throughout the year in either cultivation or drying purposes, it makes the greenhouse structure more economically feasible and does not have any operating cost

In order to make the greenhouse dryer more effective, various researchers have worked to minimize its various losses. Gupta et al. have proposed that for the small-scale greenhouse, loss of solar fraction through the north wall of the greenhouse is the most prominent loss [7]. It has attracted the attention of the researcher. There are various concepts proposed by various scientists and researchers. Jain has proposed the application of packed bed thermal storage in the north wall of the active greenhouse dryer [8]. A test was conducted to dry onion in the proposed dryer. Onion took only twenty-four hours to dry up in the proposed dryer.

The application of inclined north wall reflection (INWR) in the conventional solar greenhouse dryer as a north wall under active and passive mode has increased the drying rate and reduces the drying time [9]. An experiment was conducted during an extreme summer month as shown in Fig. 2. Bitter gourd was used to dry in the proposed dryer and it saved 16.67% of drying time.

Berrouga et al. have proposed the application of north wall made of phase change material (PCM)—$CaCl_2 \cdot 6H_2O$ in the passive greenhouse [10]. Study reveals that all inside temperatures were raised by 6–12 °C during off sunshine hour in the winter season with very few fluctuations. Prakash and Kumar have proposed the application of the mirror as the north wall of the roof type even span greenhouse dryer [11]. An experiment was conducted in the no-load conditions in the month of January in the department of Energy, Maulana Azad National Institute of Technology, Bhopal, India. Adaptive neuro fuzzy inference system (ANFIS) model has been made to predict the greenhouse room temperature and its relative humidity. The simulated value is in fair agreement with experimental value.

A hybrid greenhouse dryer is proposed which can be operated as an active mode and passive mode as required [12]. An experiment was conducted in the no-load conditions. The characteristic curves of the greenhouse dryer in both modes intercept at zero, which satisfied the result proposed by Suter and Tiwari [13]. A compressive review of all recent developments in the greenhouse drying systems are presented in this work.

2. Classification of greenhouse dryer

Kumar et al. have presented the detailed classification of the greenhouse [14]. Greenhouse dryer is mainly classified into two types based on structure (i) dome shape and (ii) roof even type.

The objective of Dome type greenhouse dryer is to maximum the utilization of global solar radiation. The advantage of the roof even type greenhouse dryer is the proper mixing of air inside the dryer.

However based on the mode of heat transfer, it is classified into two types namely (i) greenhouse dryer under passive mode and (ii) greenhouse dryer under active mode.

Each dryer can be operated in either passive (natural convection) or active mode (forced convection). The passive mode of greenhouse dryer works on the principle of thermosyphic effect. The humid air gets ventilated through the ventilator -provided at the roof or through the chimney of the dryer. Humid air is ventilated by the help of an exhaust fan provided at the ventilator. It is generally provided in the upper portion of the west wall.

2.1. Greenhouse dryer under passive mode

Jain and Tiwari have proposed a greenhouse dryer under natural convection mode to dry cabbage and peas and at the same time; the same amount of these crops were also dried in open sun as shown in Fig. 3 [15]. Convective mass transfer coefficient (h_c) was calculated for the both modes of drying. The study showed that the crop dried inside the greenhouse dryer under passive mode has lower h_c than the one with open sun drying. The convective mass transfer coefficient was also evaluated for jaggery drying under roof type even span greenhouse dryer [16]. At the beginning of the drying process, the value of h_c was higher and decreased with time. Farhat et al. have proposed polyethylene greenhouse dryer under natural convection mode for drying of

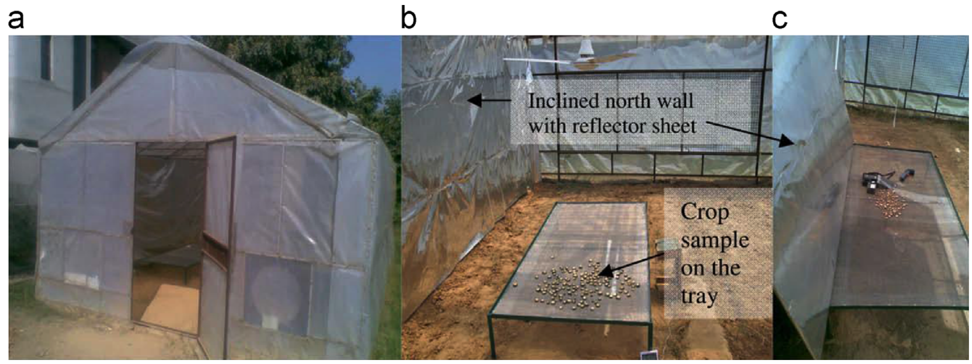

Fig. 2. Pictorial view of improved greenhouse dryer (a) outside view (b and c) inside view [9].

Fig. 3. Experimental setup for open sun drying and greenhouse drying under passive mode [15].

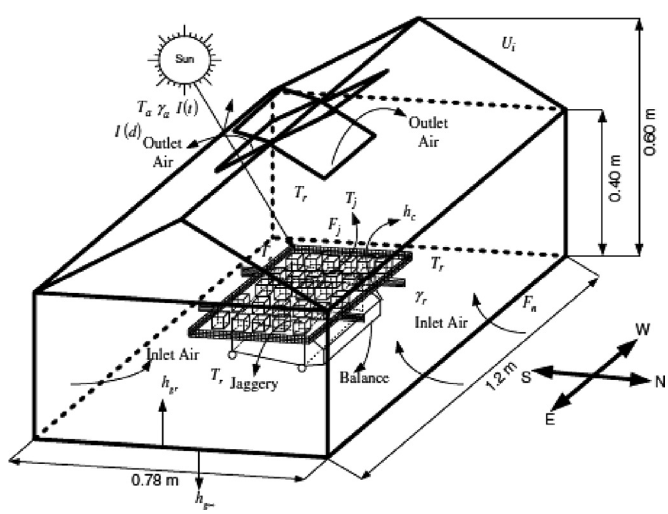

Fig. 4. A schematic view of greenhouse dryer under natural convection mode for jaggery drying [20].

pepper [17]. This leads to more than an 83% reduction of mass of the pepper at the end of the drying process.

Koyuncu has proposed two new heavy-duty greenhouse dryers under natural convection mode [18]. Dryers were investigated on both no-load conditions as well as load conditions. A test was conducted to dry pepper in these dryers and compared with

Fig. 5. Experimental setup for greenhouse drying under active mode [16].

natural drying under the same climatic conditions. Pepper dried in the dryer was superior in quality and the drying procedure was two and a half times more efficient than natural drying.

Kumar and Tiwari have studied the effect of the shape and size of jaggery on the evaluation of convective mass transfer coefficient for greenhouse dryer [19]. An experiment was conducted for three different dimensions ($0.03 \times 0.03 \times 0.01$ m^3, $0.03 \times 0.03 \times 0.02$ m^3, and $0.03 \times 0.03 \times 0.03$ m^3) and two different sets—0.75 kg and 2.0 kg. Convective mass transfer coefficient for jaggery with dimensions $0.03 \times 0.03 \times 0.02$ m^3 in the natural convection mode was more than that in force convection mode of the dryer.

Thermal modelling of roof type even span greenhouse dryer for jaggery drying was proposed by Kumar and Tiwari as shown in Fig. 4 [20]. It was applied to predict the jaggery temperature, greenhouse air temperature, and jaggery mass during drying. It was validated by the experimental result. Sacilik et al. have proposed the mathematical model for solar tunnel greenhouse dryer for the drying of tomato [21]. It was compared with open sun drying for tomato. The dryer dried the tomato in four days but open sun drying took five days to dry the tomato. The quality and colour of the dried tomato in the dryer was far superior to naturally dried tomato. Ten different thin mathematical models were applied to the experimental drying curves. The approximation of the diffusion model is found to be the best fit as compared to others models.

The energy and exergy analyses of greenhouse under passive mode for fish drying are presented in [22]. Energy analysis was used to predict the fish surface temperature, greenhouse room temperature and moisture evaporated during drying. The predicted value is validated by the experimental values and its coefficient of correlation varies from 0.94–0.99. The thin layer **drying kinetics** of *Amaranthus cruentus* grain occurred in the solar tent dryer under passive mode [23]. The drying rack is inside the dryer having two racks—top and bottom. The drying time of the product was 7 h and at the end, the moisture content was 7% (dry basis). Temperature inside the tent dryer varies from 31.2–54.7 °C and its relative humidity ranges from 22–34%. The quality of tent

Table 2
Comparative analysis of greenhouse dryer under passive mode.

S. no.	Author	Concluding remarks on previous research	References
1	Jain and Tiwari	Experiment was conducted to dry cabbage and pea in the greenhouse dryer in dome shape and in open sun drying simultaneously. The convective mass transfer coefficient (h_c) is calculated. The convective mass transfer coefficients for the dryer is higher than open sun drying for both crops.	[15]
2	Tiwari et al.	The drying of low moisture content crop such as jaggery in the greenhouse dryer of even span roof type was being studied. In the beginning of the drying process, the value h_c is high but as drying process continued, h_c value started to decrease.	[16]
3	Farhat et al.	Pepper was proposed to dry in polyethylene greenhouse dryer. The 83% moisture reduction takes place in this process.	[17]
4	Koyuncu	The two new heavy-duty greenhouse dryers have been proposed to dry pepper. Drying was also conducted in the natural drying process. Result shows that pepper dried in the dryer is found to be more hygienic. The drying performance of the dryer is 2.5 times more efficient than that open sun drying.	[18]
5	Kumar and Tiwari	The effect of h_c in drying in greenhouse dryer under active and passive mode for jaggery of different shape and size ($0.03 \times 0.03 \times 0.01 m^3$, $0.03 \times 0.03 \times 0.02\ m^3$, and $0.03 \times 0.03 \times 0.03\ m^3$) have been studied for two different sets of mass namely 0.75 kg and 2.0 kg. The jaggery having dimensions $0.03 \times 0.03 \times 0.02\ m^3$ has higher h_c than greenhouse dryer under passive mode. However for other two shapes of jaggery, the value of h_c for greenhouse dryer under active mode is higher than others.	[19]
6	Kumar and Tiwari	The thermal modelling for greenhouse dryer having even span roof has been proposed for jaggery drying. The model is applied to predict the greenhouse room temperature, jaggery temperature and mass of jaggery during drying. Predicted value was validated with experimental value and it is found to be in good agreement.	[20]
7	Sacilik et al.	The ten different mathematical models for solar tunnel type greenhouse dryer for tomato drying have been proposed. Experiment was conducted simultaneously in the open sun drying mode. The drying time in the dryer was quite low as compared to open sun drying mode and product was also more nutrient and hygienic. The approximation of diffusion model is found to be the best fit as compared to others models.	[21]
8	Tiwari et al.	The energy and exergy analysis for the greenhouse drying has been proposed for drying of fish. Predicted value is found to be in fair agreement with experimental value.	[22]
9	Ronoh et al.	The drying of *Amaranthus cruentus* grain in the solar tent dryer and natural drying have been studied. The dryer has two racks namely top and bottom. The drying time of crop which is dried in dryer is found to be low as compared to others. The crop dried in the dryer is found to be more nutrient and hygienic than naturally solar dried crop.	[23]
10	Prakash and Kumar	Adaptive Neuro Fuzzy Inference System (ANFIS) model was used to predict the jaggery temperature, greenhouse room temperature and mass of jaggery during drying. It is validated with experimental result. Study shows that ANFIS is able to predict better than thermal modelling.	[24]

dried *Amaranthus cruentus* grain was far superior to that in open sun drying.

Prakash and Kumar have presented the ANFIS (Adaptive Neuro Fuzzy Inference System) model for the greenhouse dryer under active mode for jaggery drying [24]. ANFIS Model was used to predict the jaggery temperature, greenhouse room temperature and jaggery mass during drying. The predicted value of these parameters was validated by the experimental results. A good co-relation between predicted and experimental data has been observed. The comparative analysis is presented in Table 2.

2.2. Greenhouse dryer under active mode

Condori and Sarvavia have presented evaporation rate in two different types of forced convection greenhouse driers—single chamber and double chamber [25]. For greenhouse dryer under active mode, there are two energy sources namely the air saturation deficit and the incident global solar radiation. There are two new concepts are proposed—the generalized drying curve and dryer performance curve. The simulation results reveal that by improving the use of drying potentials, production rate of the dryer will improve. Experimentation was conducted on the proposed dryer to dry sweet pepper. Results reveal that double chamber greenhouse dryer is 87% more productive than single chamber for the same area.

A low cost tunnel greenhouse dryer under force convection mode is design, developed and tested on sweet pepper and garlic [26]. It is made of a plastic transparent wall with a manually driven line of carts with several staked drying trays including exhaust fan. Drying tray receives the solar radiation though the transparent plastic wall of the dryer. The laboratory model of the dryer was constructed in the north of Argentina. Experimental results, in clear sky conditions shows good drying behaviour with a good drying rate, with an acceptable limit of final moisture content and colour of the dried product.

Fig. 6. Experimental setup of greenhouse drying under forced convection for jaggery drying [19].

Condori and Saravia have proposed an analytical study of tunnel greenhouse dryer, which describes its drying performance [27]. The dryer is considered as a solar collector and there is a linear relationship between incident global radiation and the output temperature. The Dryer performance is calculated as a function of the drying potentials by the help of dryer characteristic functions. Cabbage and peas were dried in the three modes of drying—open sun-drying, greenhouse dryer under natural convection and under force convection in the climate of New Delhi, India [15]. The convective mass transfer coefficient was calculated for all three modes of drying. At the initial stage of drying, the value of convective mass transfer coefficient is double in the force convection mode than in natural convection mode of the greenhouse dryer.

The convective mass transfer coefficients of different masses of jaggery drying in the roof type even span greenhouse dryer under natural and forced convection were evaluated by Tiwari et al. [16] (Fig. 5). Jaggery was dried in the forced convection mode at a faster rate than natural convection mode. The convective mass transfer

Table 3
Comparative analysis of greenhouse dryer under active mode.

S. no.	Authors	Concluding remarks on previous research	References
1	Condori and Saravia	The studies of evaporation rate of two different greenhouse dryers have been done. One greenhouse has one drying chamber and another one has two drying chambers. Pepper was used to dry in these dryers. Result shows that double chamber greenhouse dryer is 87% more efficient than others.	[25]
2	Condori et al.	The low cost tunnel dryer for drying of sweet pepper and garlic has been studied. The drying process for dryer have good drying rate.	[26]
3	Condori and Saravia	A mathematical study to describe drying performance of solar tunnel greenhouse dryer has been proposed. Dryer was considered as solar collector and output temperature was directly proportional to incident global radiation.	[27]
4	Kumar and Tiwari	The thermal modelling for the greenhouse dryer under active mode having even span roof is presented for drying of jaggery. The model was used to predict the jaggery temperature, greenhouse room temperature and mass of jaggery during drying. Results show that there is fair agreement between predicted and experimental value.	[28]
5	Hossain and Bala	The study of mixed type solar tunnel dryer under active mode has been studied. Experiments were conducted to dry red and green chilli. Dryer has reduced the drying time considerably as compared to open sun drying.	[29]
6	Kumar and Tiwari	The effects of onion drying of different masses (300 gm, 600 gm and 900 gm) have been studied in the greenhouse dryer having even span roof under active mode. The h_c value increases with increase in the mass of onion.	[30]
7	Kooli et al.	The study of open sun drying and constant laboratory conditions greenhouse drying at varying atmospheric conditions for red pepper drying was conducted. The various drying parameters have been calculated.	[31]
8	Nayak and Tiwari	The energy and exergy analysis for photovoltaic/thermal integrated greenhouse dryer is presented for clear sky conditions. Predicted value was validated with experimental data.	[32]
9	Barnwal and Tiwari	The study of drying in a large size hybrid PV/T greenhouse dryer under active mode was used to dry grape. The drying performance of grapes in greenhouse dryer was compared with the natural drying as well as shade drying. The greenhouse drying was found to be superior in all perspectives.	[33]
10	Janjai et al.	The experimental and simulated study of a greenhouse dryer under active mode for drying peeled longan and banana was conducted. The exhaust fan was powered by PV module. At the same time experiment was conducted in the open sun drying. The drying time for the dryer is found to be low as compared to open sun drying.	[34]
11	Rathore and Panwar	The drying of chemically untreated grapes was done in the walk-in type cylindrical solar tunnel dryer under active mode and open sun drying. The grapes dried in dryer are found to be superior in all perspectives including shortage of drying time.	[35]
12	Janjai et al.	A large scale polycarbonate parabolic shape active greenhouse dryer having capacity of 1000 kg with black concrete floor was designed and developed. Experiment was conducted to dry the banana, chilli and coffee in dryer as well as open sun drying. The drying performance of dryer is far superior to open sun drying.	[36]

coefficient under forced convection mode is higher than natural convection mode of the dryer.

Thermal modelling of the roof type even span greenhouse dryer under forced convection mode was presented to predict the jaggery temperature, inside air temperature and mass of jaggery during drying [28]. There was fair agreement between predicted value and the experimental value. The experiment was conducted at Solar Energy Park, IIT Delhi, India for three different shapes of the jaggery of 2 kg total mass. Kumar and Tiwari have studied the effect of variation of the shape and size of jaggery under force and natural convection of greenhouse dryers on convective mass transfer coefficient as shown in Fig. 6 [19]. Jaggery having dimensions of $0.03 \times 0.03 \times 0.03$ m^3 are found to have higher convective mass transfer coefficient in the forced convection mode of greenhouse dryer than in the natural convection mode.

Hossain and Bala have presented a mixed type forced convection solar tunnel dryer [29]. A test was conducted to dry red hot and green chilli in sunny weather conditions in Bangladesh. The Photovoltaic module was applied to provide power to run the exhaust fan of the dryer. The dryer has reduced the drying time considerably and enhanced the quality of the dried product considerably. The effect of different masses (300 g, 600 g and 900 g) of onion flakes on convective mass transfer coefficient in natural and greenhouse drying under active mode was studied [30]. Experimental study revealed that the rate of drying for the greenhouse dryer was higher in comparison to the open sun drying in the off sunshine hours. The convective mass transfer coefficient increased as the mass of the onion increased.

The drying of red pepper in natural and constant laboratory conditions greenhouse drying at varying atmospheric conditions were taken place [31]. An experiment was carried out inside the wind tunnel integrated with 1000 W lamp for different outdoor conditions. The effect of various drying parameters and drying time were evaluated. Nayak and Tiwari have proposed energy and exergy analysis of photovoltaic/thermal integrated greenhouse dryer [32]. It was validated with the experimental result, which is conducted in the clear sky conditions. A large size hybrid PV/T greenhouse dryer under active mode was used to dry grape in the New Delhi climate zone [33]. The exhaust DC fan is powered by Photovoltaic panel to remove the humid inside air. The drying performance of the greenhouse dryer was compared with the natural drying as well as shade drying. The convective mass transfer coefficient was lower with respect to open sun drying however quality and colour of the dried product inside the greenhouse dryer was far superior than that in natural drying.

Janjai et al. have presented an experimental study and simulated performance of a greenhouse dryer under active mode for drying peeled longan and banana [34]. The inside humid air is ventilated by the exhaust fan powered by 50-W PV module. The peeled longan took only 3 days to get dried up in the greenhouse dryer while five to 6 days are required for open sun drying. The drying time for banana is only four days in the greenhouse drying whereas open sun drying needs 5–6 days. The quality and colour of the greenhouse dried product was much superior than naturally dried product.

Tiwari et al. have presented the energy and exergy analysis of greenhouse under active and passive mode [22]. The drying in the active mode was faster than passive mode due to the continuous removal of inside humid air. Chemically untreated grapes were dried in the walk-in type cylindrical solar tunnel dryer under active mode [35]. The drying time in tunnel dryer was seven days with a temperature gradation of 10–28 °C. The quality of the dried product was far superior to that in natural drying.

A large scale parabolic shape active greenhouse dryer having capacity of 1000 kg with black concrete floor was developed in Champasak (15.13°N, 105.79°E) in Lao Peoples Democratic Republic (Lao PDR) [36]. The dryer is covered by the polycarbonate sheet having nine DC exhaust fans powered by 50-Wp solar cell modules. A test was done to dry the banana, chilli and coffee. The drying time to dry banana in the proposed dryer was only five days however, open sun drying took seven days. The drying time for chilli was 3 days in the dryer whereas 5 days in open sun

drying. However, coffee took 2 days to dry in the proposed dryer while natural dryer took four days. The quality and colour of greenhouse dried banana, chilli and coffee was far better than that in natural sun drying. The comparative analysis of dryer is given in Table 3.

3. Conclusion

There is considerable research and field level performance of the greenhouse dryer under natural and forced convection mode all over the world. The greenhouse dryer under forced convection mode was found to be best for high moisture content crops; however the greenhouse dryer under natural convection mode was found to be best for low moisture content crops. Crops dried in the greenhouse dryer are of a superior quality and colour as compared to open sun drying. Study reveals that the PV-integrated solar greenhouse dryers are most applicable in the production of dried crop in commercial scale in Southeast Asian countries. It can be applied in the remote area since it is free from requirement of grid-connected electricity. Simulation models are proposed by the researcher to provide the design data for the selection of the optimal dryer.

References

[1] Janjai S, Bala BK. Solar drying technology. Food Engineering Reviews 2012;4:16–54.
[2] Muhlbauer W, Esper A, Muller J. Solar energy in agriculture. In: Proceedings of ISES solar world congress, Budapest; 1993, p. 23–7.
[3] Bala BK. Adaptive research on solar driers for drying mango, pineapple and fish. Annual research report, Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh, Bangladesh; 2000.
[4] Sharma A, Chen CR, Nguyen Vu Lan. Solar-energy drying systems: a review. Renewable and Sustainable Energy Reviews 2009;13:1185–210.
[5] Prakash O, Kumar A. Historical review and recent trends in solar drying systems. International Journal of Green Energy 2012;10(7):690–738.
[6] Tiwari GN. Greenhouse technology for controlled environment. New Delhi: Narosa Publishing house; 2003.
[7] Gupta R, Tiwari GN, Kumar A, Gupta Y. Calculation of total solar fraction for different orientation of greenhouse using 3D-shadow analysis in Auto-CAD. Energy and Buildings 2012;47:27–34.
[8] Jain D. Modeling the performance of greenhouse with packed bed thermal storage on crop drying application. Journal of Food Engineering 2005; 71:170–8.
[9] Sethi VP, Arora S. Improvement in greenhouse solar drying using inclined north wall reflection. Solar Energy 2009;83:1472–84.
[10] Berrouga F, Lakhala EK, Omaria ME, Faraji M, Qarniac HE. Thermal performance of a greenhouse with a phase change material north wall. Energy and Buildings 2011;43:3027–35.
[11] Prakash O, Kumar A. ANFIS prediction model of a modified active greenhouse dryer in no-load conditions in the month of January. International Journal of Advanced Computer Research 2013;3 no.1(8):220–3.
[12] Barnwal P, Tiwari A. Design, construction and testing of hybrid photovataic integrated greenhouse dryer. Journal of Agricultural Research 2008;3 (2):110–20.
[13] Sutar RF, Tiwari GN. Temperature reduction inside greenhouse. Energy 1996;21:61–5.
[14] Kumar A, Tiwari GN, Kumar S, Pandey M. Role of greenhouse technology in agricultural engineering. International Journal of Agricultural Research 2006;1 (4):364–72.
[15] Jain D, Tiwari GN. Effect of greenhouse on crop drying under natural and forced convection I: evaluation of convective mass transfer coefficient. Energy Conversion and Management 2004;45:765–83.
[16] Tiwari GN, Kumar S, Prakash O. Evaluation of convective mass transfer coefficient during drying of jaggery. Journal of Food Engineering 2004; 63:219–27.
[17] Farhat A, Kooli S, Kerkeni C, Maalej M, Fadhel A, Belghith A. Validation of a pepper drying model in a polyethylene tunnel greenhouse. International Journal of Thermal Sciences 2004;43:53–8.
[18] Koyuncu T. An Investigation on the performance Improvement of greenhouse-type agricultural dryers. Renewable Energy 2006;31:1055–71.
[19] Kumar A, Tiwari GN. Effect of shape and size on convective mass transfer coefficient during greenhouse drying (GHD) of jaggery. Journal of Food Engineering 2006;73:121–34.
[20] Kumar A, Tiwari GN. Thermal modeling of a natural convection greenhouse drying system for jaggery: an experimental validation. Solar Energy 2006; 80:1135–44.
[21] Sacilik K, Keskin R, Elicin AK. Mathematical modelling of solar tunnel drying of thin layer organic tomato. Journal of Food Engineering 2006;73:231–8.
[22] Tiwari GN, Das T, Chen CR, Barnwal P. Energy and exergy analyses of greenhouse fish drying. International Journal of Exergy 2009;6(5).
[23] Ronoh EK, Kanali CL, Mailutha JT, Shitanda D. Thin layer drying kinetics of Amaranth (*Amaranthus cruentus*) grains in natural convection solar tent dryer. African Journal of Food agriculture nutrition and development 2010;10(3).
[24] Prakash O, Kumar A. ANFIS modeling of a natural convection greenhouse drying system for jaggery: an experimental validation. International Journal of Sustainable Energy, http://dx.doi.org/10.1080/14786451.2012.724070, in press.
[25] Condori M, Saravia L. The performance of forced convection greenhouse driers. Renewable Energy 1998;13(4):453–69.
[26] Condori M, Echazu R, Saravia L. Solar drying of sweet pepper and garlic using the tunnel greenhouse drier. Renewable Energy 2001;22:447–60.
[27] Condorı M, Saravia L. Analytical model for the performance of the tunnel-type greenhouse drier. Renewable Energy 2003;28:467–85.
[28] Kumar A, Tiwari GN. Thermal modeling and parametric study of a forced convection greenhouse drying system for jaggery: an experimental validation. International Journal of Agricultural Research 2006;1(3):265–79.
[29] Hossain MA, Bala BK. Drying of hot chilli using solar tunnel drier. Solar Energy 2007;81:85–92.
[30] Kumar A, Tiwari GN. Effect of mass on convective mass transfer coefficient during open sun and greenhouse drying of onion flakes. Journal of Food Engineering 2007;79:1337–50.
[31] Kooli S, Fadhel A, Farhat A, Belghith A. Drying of red pepper in open sun and greenhouse conditions mathematical modeling and experimental validation. Journal of Food Engineering 2007;79:1094–103.
[32] Nayak S, Tiwari GN. Energy and exergy analysis of photovoltaic/thermal integrated with a solar greenhouse. Energy and Buildings 2008;40:2015–21.
[33] Barnwal P, Tiwari GN. Grape drying by using hybrid photovoltaic-thermal (PV/T) greenhouse dryer: an experimental study. Solar Energy 2008;82:1131–44.
[34] Janjai S, Lamlert N, Intawee P, Mahayothee B, Bala BK, Nagle M, et al. experimental and simulated performance of a PV-ventilated solar greenhouse dryer for drying of peeled longan and banana. Solar Energy 2009;83:1550–65.
[35] Rathore NS, Panwar NL. Experimental studies on hemi cylindrical walk-in type solar tunnel dryer for grape drying. Applied Energy 2010;87:2764–7.
[36] Janjai S, Intawee P, Kaewkiewa J, Sritus C, Khamvongsa V. A large-scale solar greenhouse dryer using polycarbonate cover: modeling and testing in a tropical environment of Lao People's Democratic Republic. Renewable Energy 2011;36:1053–62.